Photonics Technology for Space Communications Applications

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introduction

Photonics technology offers a multitude of applications and major benefits in the development of future spaceborne communications systems[1-6] with high performance and low mass/size requirements. These applications include not only signal distribution/control functions, but also optical signal processing, phased array antennas, sensors, instruments, and gyros. Figure 1 illustrates the insertion of photonic technology into spacecraft.

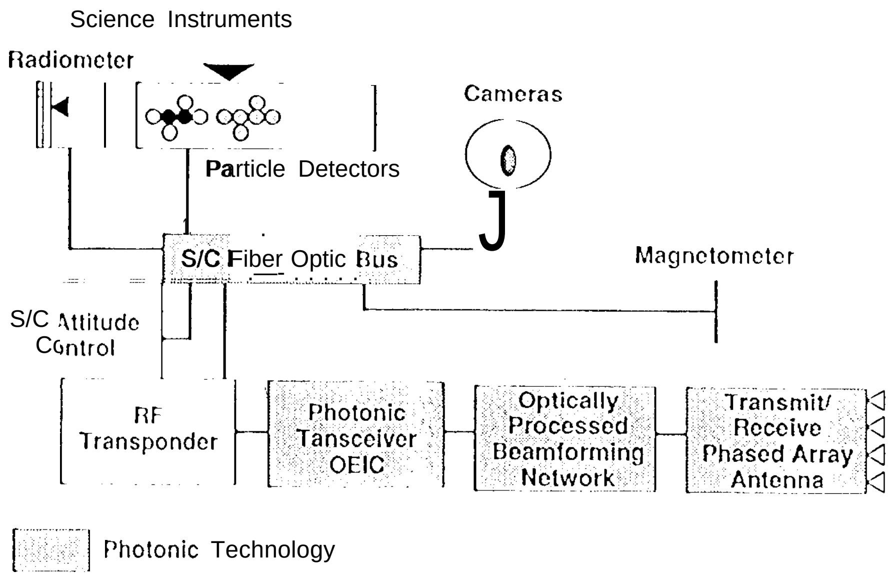

Figure 1. A System Block Diagram Illustrating the Insertion of Photonic Technology into Spacecraft

Photonic technology offers (he capability to link all spacecraft data, control, and sensors functions with the microwave communications systems within a common architecture. Both radio frequency (RF) and digital signals share a single fiber optic bus thus reducing overall system mass, and volume. Optical fibers replace common wave guide, coaxial lines and shielded wires while increasing radio frequency interference (RFI) immunity, simplifying routing, and enabling higher degrees of redundancy and/or parallelism.

The series of future NASA missions that appear to benefit most arc Mars Environmental Survey, lunar Orbiter, Focused Small Missions, and Submillimeter Research. Specific telecommunications system designs enable simultaneous transmit and receive communications with multiple rovers and micro-orbiters without expending spacecraft resources for the pointing body fixed antennas. Optical sampling,[7-10] signal processing and computing will simplify communications systems architecture in future satellite systems. ‘Ixhc other systems that will benefit include mobile, cable, and fiber optic communication links.

Although there has been a spur of activity in recent years in the technology development[3,6,7] of photonic integrated circuits (PIC) and optoelectronic integrated circuits (OEIC), very limited work has addressed the areas of reliability and cost reduction. Technology maturity, reliability, low cost and flight demonstration arc imperative in the insertion of photonic technology in the spacecraft communications applications. ‘1’able 1 provides an assessment of the state-of-the-art photonic technology.

1 able 1. State-of-the-art Technology Assessment and Challenges

Photonic Components	erformance	Mass/ Size	Power onsumptior	echnology Maturity	eliability	Cost
1. Laser/Modulator PIC	Very Good	Very Good	Good	Good	Fair	Fair
2. Optical Receiver OEIC	Very Good	Very Good	Very Good	Very Good	Fair	Fair
3. Coherent Optical Receiver OEIC	Good	Very Good	Very Good	Good	Fair	Fair
4. Transceiver OEIC	Good	Very Good	Very Good	Good	Fair	Fair
5 Laser/Amplifier PIC	Good	Very Good	Good	Good	Fair	Fair
6. Fiber-optic Components	Very Good	Best	N/A	Very Good	Good	Good
7. Fiber-optic Amplifiers	Very Good	Very Good	Very Good	Good	Good	Good
8. Modulators	Very Good	Very Good	Very Good	Good	Good	Good
9. Multiplexers/DeMultiplexers	Very Good	Very Good	Very Good	Good	Fair	Fair
10. Optical Samplers/Mixers	Fair	Very Good	Very Good	Fair	Fair	Poor
11. Photonic Switching & Signal Processing PICs	Good	Very Good	Very Good	Fair	Fair	Poor
12. PIC 8 OEIC Packages	Good	Very Good	N/A	Fair	Fair	Fair

egend: Poor Fair Good Very Good Best

PIC - Photonic Integrated circuit OEIC - Opto-Electronic Integrated circuit integrated photonic components that have been fairly well developed include laser/Ill(j(llllatoIs, optical receivers, laser/amplifiers, and fiber-op~ic components. The components requiring further R/D include optical samplers/mixers[7-10] applied to communications, photonic switching, signal processing, and higher function OEICs, and packages. '1'able 2 makes a comparison of tradeoffs between the status of photonics versus RF technology. Presently, RF has significant advantage over photonics mainly because of its maturity and proven reliability,

Table 2: Microwave and Photonic Technology Tradeoffs

Microwave/[{F- Technology	Photonic Technology
• Mature technology	• Continued R/D is essential fOt space applications
• Reli able	• fiber-optic technology well developed, and highly reliable
• Cost effective for most applications (Designable to cost)	• Cost models do not exist
• Limited bandwidth	• Lower signal distribution losses
• RF matching required	• Much wider bandwidths
• RFI/EMI shielding is necessary	• RFI/EMI immunity
• Lower port-to-port isolation	• Higher port-to-port isolation
• Higher signal dispersion	• lower signal dispersion
• Larger size and mass	• Better delay stability
	• Smaller in size and mass
	• Reduced cost potential

Space Communications System Applications

Free Space Optical Communications: The first photonic system, and the one at the highest level of readiness to be considered, is free space optical communication[1,2,4,5] (Laser Communication). Free space optical communications technology has been in development since the early 1 960's. The system offers the potential for extremely high data rates and small, power-efficient space communication terminals. This technology is very critical to the support of many future Commercial Satellite Applications and NASA requirements for Earth Observing and Planetary missions.

Several technical challenges remain in this area[1,2]. First, and most critical, is the proper technology development for pointing, acquisition, and tracking, Wc also must develop high power lasers, high bandwidth and high sensitivity receivers, and improve coherent detection methods.

Photonic Ka-band Telecommunications System: Spacecraft and Satellite communications systems use Ka-band frequencies to reduce spacecraft antenna size and mass with increased data rate performance. The current systems are not compatible with fiber optic bus architectures[3]. Such design Concepts have been evolving with joint efforts at NASA Lewis Research Center, and Jet Propulsion Laboratory. One such system shown in Figure 2, is a Ka-band phased array telecommunications system consisting of a RF transponder, a photonic transceiver OEIC, an optical signal distribution/control network, and phased array transmit/receive OEIC elements.

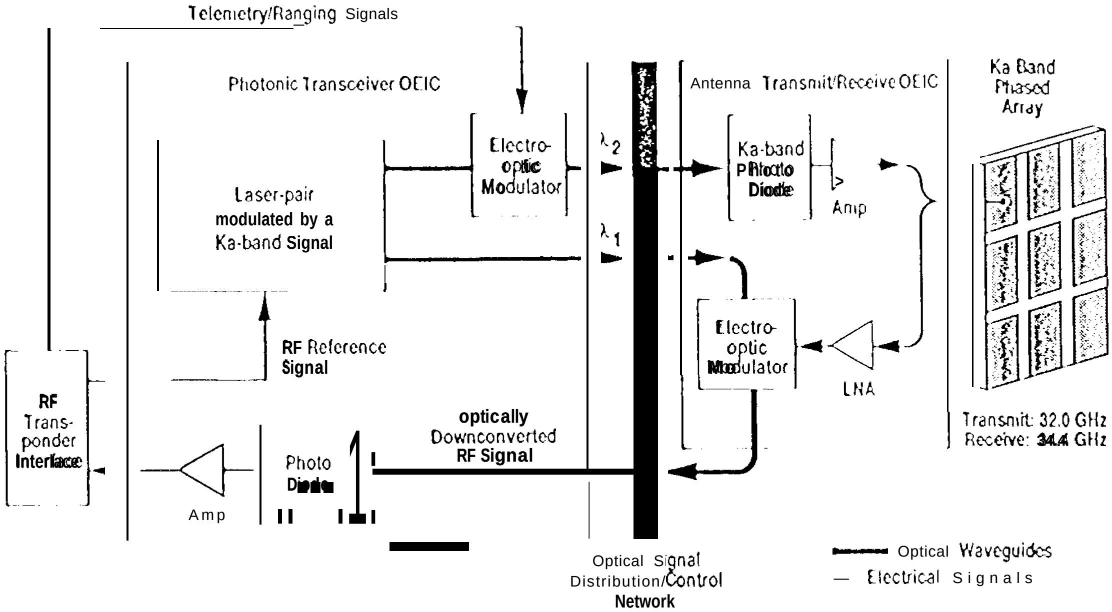

Figure 2. Photonic Ka-Band Spacecraft Telecommunications Systems Concept

The photonic transceiver OEIC consists of dual lasers, and modulators, and photo diode circuits. Several distribution and control network configurations have been identified for specific application requirements. These configurations range from single steerable beam arrays using element level optical delay to more complex multiple beam architectures using optically processed beam forming networks to both distribute and provide the RF phase gradient optically. Each architecture relies upon conversion from optical to Ka-band for transmitting and from Ka-band to optical upon receiving at the aperture level. The photonic Ka-band telecommunications system has a potential to reduce volume by a factor of ten and mass by a factor of three compared to an equivalent electronic implementation.

Optical-Sampling Downconverter for Advanced Microwave Communications Applications: Future spaceborne communications transponders require versatile high speed signal processing[7-10] and detection techniques to downconvert and process radio frequency (RF) signals ranging from 100 MHz to 35 GHz. The number of simultaneous orbit/observation missions are expected to increase in the early part of the next century. These missions require simultaneous communications capability at several different frequency bands. The use of optical sampling and detection techniques will offer excellent wideband performance, signal tracking, and reduced volume. Figure 3 shows a block diagram, an optical sampling downconverter OEIC consisting of a wideband optical switch, an injection laser diode, a sample-hold circuit, and a fast rise time pulse generator.

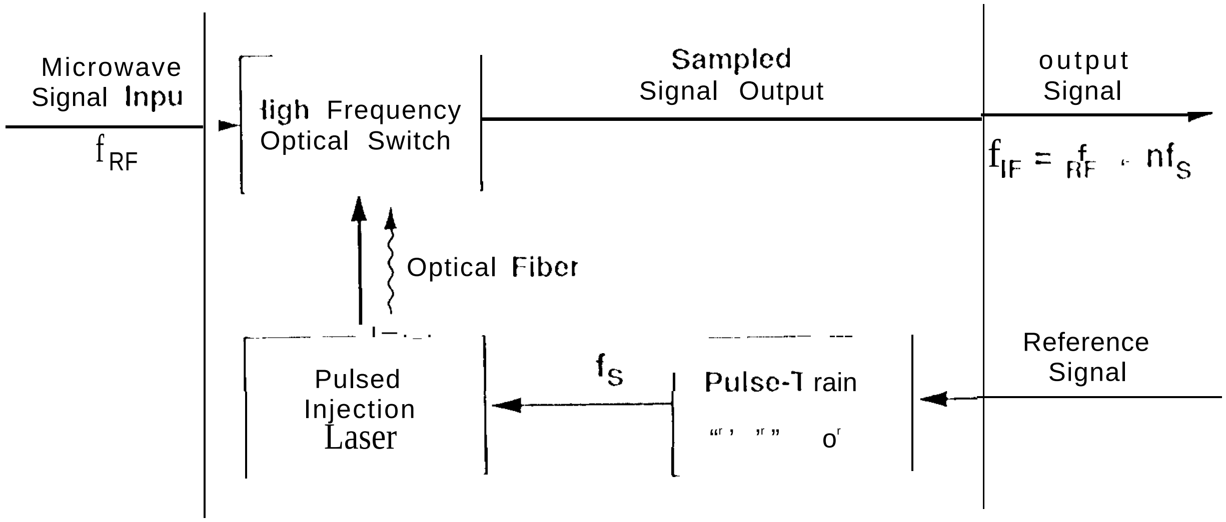

Figure 3. Optical Sampling Downconverter and Signal Processor

The optical-sampling downconverter is capable of (transforming received multi-octave-band microwave signals to intermediate frequencies (IF) for further processing. Along with ultra-wideband operation, the downconverter promises to provide direct digitization of the RF signal with low conversion loss, high isolation, and low jitter. Additional enhancements promise to simplify the receiver architecture by *eliminating most* of the analog IF circuits, including filters, IF amplifiers, and mixers. This has the potential for low power operation compared o an equivalent electronic high frequency sampling implementation.

For example, the electronic sampler designed for Deep Space Network ground receiver requires about 30 W to digitize 8 GHz RF signal. The technique can be applied to deep space transponders, Deep Space Network ground receivers, relay stations, space station receivers, satellite communications systems, and microwave instruments.

Conclusions

The photonic technology is a viable and enabling technology for long-term insertion into spacecraft and satellite communications, signal distribution, phased array, and sensor applications. The technology payoff potentials include high performance, small size, low mass, and low power. Additional benefits include high isolation, low loss/dispersion, wide bandwidth, high efficiency, and robust design. Optical sampling and signal processing of RF signals ranging from 100 MHz to 40 GHz is an enhanced technology alternative to conventional electronic processing.

Photonic technology can become more competitive, designable, reliable, and cost-effective by focussing on application oriented research rather than unique one-o - a-kind component development. System hardware development and flight experiments are needed to demonstrate performance advantages of photonic technology applied to space communications applications.

Acknowledgement

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